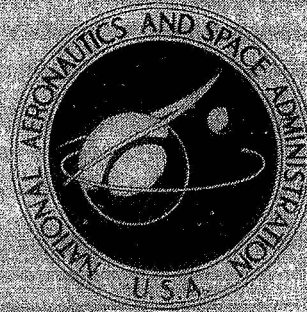


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STATISTICS CONCERNING THE APOLLO
COMMAND MODULE WATER LANDING, INCLUDING
THE PROBABILITY OF OCCURRENCE OF
VARIOUS IMPACT CONDITIONS, SUCCESSFUL
IMPACT, AND BODY X-AXIS LOADS

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SUMMARY

Statistical information for Apollo command module water landings is presented. This information includes the probability of occurrence of various impact conditions, a successful impact, and body X-axis deceleration loads of various magnitudes. Analysis was performed for the Apollo command module structure, which has a recovery weight (parachute-spacecraft system) of 5307.1 kilograms (11 700 pounds) and a center of gravity and parachute riser attach point that result in a 27.5° hang angle while on the main parachutes. The results of this analysis apply to the parachute/spacecraft configuration for Apollo 10 and subsequent missions, provided that the primary structural design remains unchanged and the weight and hang angle are not varied more than ± 226.8 kilograms (± 500 pounds) and $\pm 1.6^\circ$, respectively.

The impact condition data were determined by a statistical analysis (Monte Carlo technique) using an analytical model which describes the angular and velocity relationships of the parachute/spacecraft-impact surface system. The effects of the number of parachutes, surface wind, and sea-state conditions were investigated for the anticipated impact conditions resulting from an Apollo parachute/command module system impacting in open waters. The results of this analysis are presented in terms of (1) the probability of occurrence of the various impact conditions (i. e., normal velocity V_N , tangential velocity V_T , and the impact angle θ), (2) the probability of successful impact with regard to structural capability, and (3) the probability of occurrence of spacecraft body X-axis deceleration of the various magnitudes resulting from the impact conditions.

For surface winds fixed and operationally constrained to a limit of 28.5 knots, the mean V_N , V_T , and θ are 8.96 m/sec (29.4 ft/sec), 19.4 m/sec (63.5 ft/sec); and 27.9° , respectively; the probability of successful impact is 0.98665; and the body X-axis mean deceleration is 7.76g.

INTRODUCTION

The Apollo command module (CM) structure was initially designed to sustain touchdown loads relative to a recovery weight of approximately 3628.8 kilograms (8000 pounds). However, for various reasons, extensive modifications increased the CM weight to such an extent that the design margin of the structure required reevaluation. Concurrent with this reevaluation, an evaluation of the body X-axis deceleration magnitudes was also made. The results of this evaluation are presented.

To perform an evaluation of the CM structural capability, it was necessary to determine both the range of impact conditions (velocity, attitudes, and impact surfaces), which the CM might experience upon landing on the ocean surface, and the relation of these impact conditions to landing loads. Based on this information, a determination was made of the number of times structural damage that would be hazardous to the crew would occur.

Information of a statistical nature concerning the expected impact conditions resulting from CM water landings is presented. This information is discussed in terms of (1) the probability of occurrence of the various impact conditions (i. e., normal velocity V_N , tangential velocity V_T , and the impact angle θ), (2) the probability of successful impact with regard to structural capability, and (3) the probability of occurrence of spacecraft body X-axis deceleration of the various magnitudes resulting from the impact conditions.

SYMBOLS

As an aid to the reader, where necessary, the original units of measure have been converted to the equivalent value in the Système International d'Unités (SI). The SI units are written first, and the original units are written parenthetically thereafter.

g	gravitational constant, m/sec^2 (ft/sec^2)
$\underline{k'}$	unit vector in Z_{TP} direction transformed into the CM axis system
$TH2R, [a_{ij}]$	transformation matrix describing the relation of the local horizontal axis system to the riser axis system
$TH2TP, [c_{ij}]$	transformation matrix describing the relation of the local horizontal axis system to the impact-tangent-plane axis system
$TR2CM, [b_{ij}]$	transformation matrix describing the relation of the riser axis system to the CM axis system
$TTP2CM, [d_{ij}]$	transformation matrix describing the relation of the impact-tangent-plane axis system to the CM

u, v, w	orthogonal velocity components, m/sec (ft/sec)
u'	velocity component at impact, m/sec (ft/sec)
V	velocity, m/sec (ft/sec)
\vec{V}	velocity vector, m/sec (ft/sec)
W	weight of combined spacecraft and parachute system
X, Y, Z	coordinate system reference axes
γ	included angle between the impact tangent plane and the local horizontal, deg
ϵ	angle between the direction of the impact-tangent-plane motion and the projection of X_{TP} into the horizontal plane, deg
θ	included angle between the $Y_{CM}-Z_{CM}$ plane and impact tangent plane, deg
λ	angle between the wind direction and the vertical plane containing the X-axis of the riser axis system, deg
μ	angle between the wind direction and the horizontal component of the impact-tangent-plane movement, deg
μ'	the sum of ϵ and μ , deg
σ	Gaussian standard deviation
τ	hang angle, negative rotation about Y_{CM} measured between X_{CM} and the X-axis of the riser axis system, deg
ϕ	roll angle, rotation about X_{CM} , deg
ϕ'	rotation about X_{CM} prior to τ rotation, deg
Ω	rotation about Y_R , describing deviation of the X-axis of the riser axis system, deg
Subscripts:	
CM	relates to the CM axis system
H	relates to the local horizontal axis system
I	describes impact surface velocity components

N	normal
O	describes velocity components of the CM center of gravity (c. g.) resulting from oscillatory movements of the riser axis system with respect to the local horizontal axis system
R	relates to the riser axis system
T	tangential
TP	impact-tangent-plane axis system
W	describes velocity components of the CM c. g. in the horizontal coordinate system

METHOD OF ANALYSIS

Mathematical Program for Simulated Water Impacts

To assess the potential loads encountered by the CM during water landings, a comprehensive knowledge of the impact velocity and orientation of the CM is required. An analytical model was developed which describes the angular and velocity relationships between the CM and the impact surfaces as functions of atmospheric, parachute/CM-system, and impact-surface dynamic conditions (ref. 1). From this model, a computer program was designed which calculates conditions for a CM water impact and provides a means of determining the impact parameters (normal velocity V_N , tangential velocity V_T , roll angle ϕ , and pitch angle θ) relative to the impact surface for a given set of input parameters. These input parameters (fig. 1) include (1) the angles λ , Ω , ϕ , and τ which describe CM orientation on the parachutes; (2) the velocity vectors \vec{V}_W , \vec{V}_O , and \vec{V}_I which describe horizontal and vertical motions of the CM, CM movement as a result of riser oscillation, and vertical motion of the water, respectively; and (3) the angles μ' (wave direction) and γ (wave angle) which describe the orientation of the impact surface. A flow diagram illustrating the sequential use of the input data and the resulting output quantities is presented in figure 2.

Monte Carlo Statistical Technique

The term "Monte Carlo" refers to problem solution by determining the average solution of a problem from a large number of individual random events. In this case, it is assumed that the characteristics of the impact conditions can be obtained from the statistics of a large sample of individual impact cases (events) where the variables used in each case are random and based on probability distributions determined or assumed for the variables.

The random variables used in computing the sample cases were obtained by a technique based on a probability integral transformation. Random numbers, uniformly

distributed between 0.0 and 1.0, were obtained by specifying a system function on a digital computer system. The random functions are defined in terms of cumulative distribution functions (CDF's). The random variable is then generated by entering the uniform number on a graph or table of the CDF and reading the resulting random variable. Thus, the adaptation of the Monte Carlo technique to the mathematical program to calculate impact values for a single simulated impact included (1) independent selection of a random number for each respective input parameter, (2) selection of a representative value for each input parameter from the CDF of the respective parameter as a function of the random number, and (3) substitution of the representative value of each input parameter into the mathematical program to solve for the impact parameters.

Cumulative Distribution Function

A CDF is established by the integration of a relative frequency distribution. The relative frequency distribution is determined by (1) establishing the range of a parameter by its upper and lower boundary, (2) dividing this range into class intervals of equal magnitude for some practical number of class intervals, and (3) accumulating the number of times a value of the parameter falls within each class interval. Thus, the relative frequency distribution reflects the number of occurrences of a particular value within each particular class interval, and the CDF indicates the probability of occurrence of a particular value within the range of possible values.

DATA SOURCE

The required input parameters consist of (1) the parameters describing spacecraft attitude and velocity which are functions of the atmospheric environment during descent (referred to as atmospheric parameters) and (2) the parameters describing the velocity and attitude of the impact surface at the time of impact (referred to as surface parameters). The required CDF's for the various input parameters, as derived from either test data or logic, are presented herein.

Atmospheric Parameters

The Euler angles λ and ϕ , representing two attitude angles analogous to roll angles, have equal probability of occurrence for any angle between 0° and 360° . The CDF data shown in table I illustrate a uniform relative frequency distribution and are applicable to both λ and ϕ .

The Euler angle τ represents the steady-state attitude maintained by the CM relative to the X-axis of the parachute riser axis system. This angle is a function of the center of gravity and parachute attach point of the CM. Consequently, variations in τ result from center of gravity and rigging tolerances. The CDF data shown in table II illustrate a normal distribution with a mean value of 27.5° and a standard deviation of $\pm 1.6^\circ$ in keeping with Apollo specifications.

The Euler angle Ω represents the angular oscillatory motion about the local vertical experienced by the CM while suspended by the parachutes. Because this angle

is a function of the number of parachutes, there are two possible CDF's: one representing two parachutes deployed and one representing three parachutes deployed. The representative magnitudes and frequencies were determined through experimental data (Block II Increased Capability Program, Joint Parachute Test Facility Range Operations), and the resulting distributions are presented in table III.

The velocity component v_W represents the descent velocity experienced by the CM while suspended by the parachutes. It is a function of both CM weight and the number of parachutes deployed. Table IV shows the CDF for v_W determined from experimental data using the updated weight of 5368.4 kilograms (11 835 pounds). The original data were based on a CM weight of 5896.8 kilograms (13 000 pounds) for either two parachutes or three parachutes. For CM weights other than 5896.8 kilograms (13 000 pounds), the descent velocity must be scaled by the square root of the ratio of weights (new weight/5896.8).

The velocity component u_W represents the horizontal surface wind (windspeed approximately 6.09 meters (20 feet) above sea level). This component can be used in either of two ways in the mathematical program: (1) held constant at some value to provide results representing an operational wind limit or (2) varied by the use of the Monte Carlo technique and by using the CDF shown in table V to provide a set of results for a broad range of possible windspeeds. Inasmuch as the center of pressure of the parachute canopy is approximately 45.7 meters (150 feet) above the surface at the time of spacecraft impact, the surface wind velocity is extended to 45.7 meters (150 feet) above sea level through the use of the power-law equation with an exponent of 0.14 (ref. 2) in order to provide a more realistic wind velocity u'_W (the velocity acting on the parachute system at impact). In addition to the wind profile, the effects of wind gusts are also considered. Gust components at approximately 45.7 meters (150 feet) above sea level are assumed to be normally distributed about a mean of zero with a standard deviation of 4.5 knots. In the absence of known data describing the parachute/CM-system gust response (a function of the magnitude and duration of gusts), a gust-response factor of 0.5 was arbitrarily selected which reduced the standard deviation of the gust distribution to 2.25 knots. By random selection in the range of $\pm 5\sigma$ deviations, the gust component was determined and assumed to act colinearly with horizontal wind velocity.

Surface Parameters

The required input parameters μ' and γ describing the orientation of the impact tangent plane were calculated from a sea model developed at the NASA Manned Spacecraft Center (MSC). The surface velocity \vec{V}_I was computed within the program. These values were selected as a function of the surface wind (u_W at 6.09 meters (20 feet) above sea level).

RESULTS

Analyses were performed to determine the probability of occurrence of various impact conditions, the probability of successful impact, and the probability of various magnitudes of the spacecraft body X-axis deceleration. The data presented represent 100 000 case samples (simulated impacts) for each set of wind conditions and each set of percent probability data of a two-parachute case.

Probability of Occurrence of Various Impact Conditions

A statistical analysis of the parameters describing the impact conditions V_N , V_T , and θ was performed to provide information concerning the most probable values relative to the mean, as well as determining the CDF for each of the parameters involved.

The data, representing the CDF of the impact parameters for each wind condition and variation in percent probability of a two-parachute case, are presented in figures 3 to 10. Each figure includes the CDF for each of the three impact parameters representing that particular set of impact conditions. As was previously stated, the CDF of a parameter indicates the probability of occurrence of a particular value within the range of possible values of that parameter. Therefore, referring to figure 3 as an example, the data presented indicate that 90 percent of the time the values for the three parameters shown would be equal to or less than 10.2 m/sec (33.5 ft/sec), 21.2 m/sec (69.5 ft/sec), and 35° . This information can be used either for a quick assessment of the potential velocities and attitudes to be anticipated or to provide initial conditions for actual hardware testing.

Figure 3 presents the CDF for the surface winds fixed and operationally constrained to a limit of 28.5 knots and a 1-percent probability of a two-parachute case. To evaluate the significance of variations in the probability of a two-parachute case, figures 4 and 5 present the CDF's for the previously mentioned surface wind with 25- and 100-percent probabilities of two-parachute cases, respectively. Figures 6 and 7 show the effect on the CDF's for fixed surface winds of 24.5 and 32.5 knots, respectively, with a 1-percent probability of a two-parachute case. To evaluate the effect of wind variability, the data presented in figure 8 illustrate the results for a variable surface wind (0 to 28.5 knots) and a 1-percent probability of a two-parachute case. To evaluate the effect of sea state, figures 9 and 10 present the CDF's for a calm sea with fixed (28.5 knots) and variable (0 to 28.5 knots) surface winds, respectively, and a 1-percent probability of a two-parachute case.

Table VI provides statistics of the impact velocities and attitude for the wind-speeds and probability of the two-parachute cases considered. To provide the broadest possible information regarding the impact parameters, table VI presents the mean and the 0.3- and 99.7-percent probability values for each of the parameters.

Probability of Successful Impact

The probability of successful impact was determined by comparing the expected impact conditions, resulting from variations in wind velocity and/or percent probability of two-parachute cases, with the structural capability lines (representing factors of safety of 1.0, 1.1, and 1.5) of the CM to ascertain the number of times the structural capability was exceeded.

This comparison indicates the probable success or failure for a particular landing. To provide a visual representation of the distribution of the impact parameters with regard to the structural criteria, comparisons of the structural capability lines with the predicted impact conditions (as represented by scatter diagrams) are presented in figure 11. This figure is composed of two parts: part (a) presents a plot of V_N opposed to θ as compared to the normal structural capability line, and part (b) presents a plot of V_T opposed to θ as compared to the tangential structural capability line.

The construction of the structural capability lines resulted from an extensive effort by the Structures and Mechanics Division (SMD) of MSC based on information concerning the structural integrity of the CM. This information was determined by evaluations (hardware testing) of those areas critical to crew survival (i.e., CM aft bulkhead face sheet, forward hatch, sidewall, astrosextant area, etc.). To provide the most comprehensive review of the anticipated probability of a successful landing, structural capability lines for factors of safety of 1.0, 1.1, and 1.35 were used (ref. 3). The range of validity of these capability lines is considered to be ± 226.8 kilograms (± 500 pounds) of the 5307.1-kilogram (11 700 pounds) CM.

The probability of success was assessed for that set of wind, wave, and probability of a two-parachute case data by determining the number of successful combinations (both V_N and V_T) for a particular θ and dividing by the number of trials (100 000). For example, figure 11, which represents the distribution of water impact conditions for a fully developed sea with a 28.5-knot surface wind and a 1-percent probability of a two-parachute case, depicts the number of times structural capability was exceeded, or the successes for various values of V_N and V_T , respectively. By actual count there were 61 and 425 occurrences of structural capability being exceeded for V_N and V_T , respectively. The probability, then, of successful impact equals 0.99514.

Table VII summarizes the various initial conditions considered, the number of times structural capability was exceeded, and the individual effects of the various values of V_N and V_T on the probability of success for three sets of factor-of-safety capability lines.

Probability of Various Magnitudes of the Spacecraft Body X-Axis Decelerations

The probability of occurrence of spacecraft body X-axis deceleration magnitudes was calculated by using empirical data representing the relationship between

deceleration, normal velocity, and impact angle data for the impact conditions considered. This relationship is presented in figure 12. Inasmuch as the empirical relationship for determining the load is independent of the tangential velocity, the effect of surface windspeeds on deceleration is minimal. However, surface winds influence the various degrees of sea state which in turn affect θ . Consequently, rather than introduce a new parameter representative of sea state, the results are presented in terms of surface winds.

To make the presentation concise, the results were consolidated so that the data illustrated would represent the lower and upper limiting conditions. The data presented in figure 13 illustrate the probability distribution function for body X-axis deceleration loads as determined for a fully developed sea with a 28.5-knot surface wind, and both 1-percent and 100-percent probabilities of a two-parachute case.

To illustrate the effects of various fully developed sea states, additional sets of impact conditions were determined for a variety of fixed surface winds which ranged from a calm sea (wave slope equal to zero) to a sea state representative of a surface wind of 32.5 knots with a 1-percent probability of a two-parachute case. Figure 14 presents the probability distribution function of the deceleration loads for the minimum and maximum sea states with a 1-percent probability of a two-parachute case. Based on the statistical information obtained from the previously discussed data, the data presented in figure 15 illustrate the variation of the body X-axis decelerations with fixed surface winds for given probabilities of occurrence.

In addition to the data presented in figure 14, the statistical analysis indicates that the anticipated loads (the loads most frequently occurring) are from approximately 5.5g for a calm sea to 3.5g for a fully developed sea state representative of a 32.5-knot surface wind.

To explain the higher probability of occurrence of lower g-levels for the fully developed sea than for the calm sea, an examination must be made of those parameters (normal velocity and impact angle) that contribute significantly to the differences between the two extreme cases. In both cases, for either parameter, the means are nearly equal; however, with regard to variance, both parameters for the fully developed sea are roughly nine times that of a calm sea. This difference is reflected in the relative frequency distributions presented in figure 16. The data in figure 16 indicate that the greater variance for a fully developed sea in either parameter produces a greater variance in the expected g-levels. Therefore, for a calm sea, the load spectrum is narrow, remaining close to values which correspond to approximately 5.5g. For a 32.5-knot surface wind, the impact angle spectrum becomes significantly wider, increasing the bounds of the load spectrum and causing the preponderance of landing loads to be at lower g-levels.

Table VIII summarizes the parameter variations, the mean, and the 0.3- and 99.7-percent cumulative probability values for the body X-axis deceleration loads.

CONCLUDING REMARKS

A statistical approach to the problem of defining the distribution of the relevant impact parameters and body X-axis deceleration loads has been made. To ensure complete coverage of the anticipated impact conditions, the analysis was made for various wind conditions (which reflect a fully developed sea state) and/or varying percent probability of a two-parachute case. Additionally, to provide some insight into the effect of a fully developed sea, two sets of data were calculated: (1) a calm sea (wave slope equal to zero) with variable windspeed and (2) a calm sea with surface winds fixed and operationally constrained to a limit of 28.5 knots.

The results of this analysis are presented in both cumulative distribution function and tabular data. These results include (1) the probability of occurrence of the impact conditions (i. e., normal velocity V_N , tangential velocity V_T , and the impact angle θ), (2) the probability of successful impact with regard to structural capability, and (3) the probability of occurrence of spacecraft body X-axis acceleration magnitudes resulting from the impact conditions.

The statistical results indicate that, based on a fully developed sea with a surface windspeed limit of 28.5 knots and a 100-percent probability of a two-parachute case, the probability of success would be 98.7 percent (0.98665) or greater. Similarly, the body X-axis deceleration loads, for the same range of conditions, may be as high as 39.5g, but there is a 60-percent probability that this load will be 12g or less.

The results of this analysis, unless otherwise noted, are a function of the Apollo command module alinement and dynamic behavior. Consequently, the results are applicable to Apollo 10 and subsequent missions, provided that the primary structural design remains unchanged and the weight and hang angle are not varied more than ± 226.8 kilograms (± 500 pounds) and $\pm 1.6^\circ$, respectively.

Manned Spacecraft Center
National Aeronautics and Space Administration
Houston, Texas, August 23, 1971
914-50-11-09-72

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TABLE I. - CUMULATIVE DISTRIBUTION FUNCTION FOR THE
AZIMUTH ANGLE^a λ AND THE ROLL ANGLE ϕ

λ and ϕ range, deg	Cumulative frequency	λ and ϕ range, deg	Cumulative frequency
-186	0.00	-6	50.00
-174	3.33	6	53.33
-162	6.66	18	56.66
-150	10.00	30	60.00
-138	13.33	42	63.33
-126	16.66	54	66.66
-114	20.00	66	70.00
-102	23.33	78	73.33
-90	26.66	90	76.66
-78	30.00	102	80.00
-66	33.33	114	83.33
-54	36.66	126	86.66
-42	40.00	138	90.00
-30	43.33	150	93.33
-18	46.66	162	96.66
		174	100.00

^aAs measured between the windspeed and the vertical plane containing the parachute X-axis of the riser axis system.

TABLE II. - CUMULATIVE DISTRIBUTION FUNCTION FOR
THE PARACHUTE HANG ANGLE^a τ

τ range, deg	Cumulative frequency	τ range, deg	Cumulative frequency
25.90	0.0	27.50	50.00
26.05	.13	28.00	84.13
26.22	.47	28.45	97.72
26.55	2.28	28.78	99.53
27.00	15.87	28.95	99.87
		29.10	100.00

^aMeasured between the X_{CM} -axis and the parachute X-axis of the riser axis system.

TABLE III. - CUMULATIVE DISTRIBUTION FUNCTION FOR
THE PARACHUTE SWING ANGLE^a Ω

(a) Two parachutes

Ω range, deg	Cumulative frequency	Ω range, deg	Cumulative frequency
0.0	0.0	5.0	88.09
.5	2.47	5.5	91.41
1.0	10.06	6.0	94.64
1.5	19.44	6.5	96.69
2.0	30.61	7.0	98.22
2.5	45.10	7.5	98.84
3.0	57.47	8.0	99.32
3.5	67.97	8.5	99.66
4.0	76.07	9.0	99.87
4.5	83.23	9.5	100.00

(b) Three parachutes

Ω range, deg	Cumulative frequency	Ω range, deg	Cumulative frequency
0.0	0.0	3.5	93.54
.5	7.03	4.0	96.66
1.0	23.09	4.5	98.67
1.5	41.71	5.0	99.56
2.0	61.99	5.5	99.78
2.5	75.48	6.0	99.89
3.0	87.18	6.5	100.00

^aA measurement of the deviation of the parachute X-axis of the riser axis system from the vertical.

TABLE IV. - CUMULATIVE DISTRIBUTION FUNCTION FOR THE RATE OF DESCENT
OF THE COMMAND MODULE ON THE MAIN PARACHUTE^a v_W

(a) Two parachutes

v_W range		Cumulative frequency
m/sec	ft/sec	
9.17	30.10	0.0
9.42	30.89	.35
9.57	31.41	1.05
9.73	31.93	4.91
9.89	32.46	8.59
10.05	32.98	16.13
10.21	33.50	26.13
10.37	34.03	36.31
10.53	34.55	47.89
10.69	35.07	58.77
10.85	35.60	72.10
11.01	36.12	87.71
11.17	36.65	95.78
11.33	37.17	98.59
11.49	37.69	99.47
11.65	38.22	99.65
11.81	38.74	100.00

^aThese data are based on a CM updated weight of 5368.4 kilograms (11 835 pounds). To account for the updated weight of the CM, a correction factor $v_W(\text{new}) = v_W(\text{old}) \sqrt{W(\text{new})/W(\text{old})}$ was used. Data for the updated CM are currently being made available.

TABLE IV. - CUMULATIVE DISTRIBUTION FUNCTION FOR THE RATE OF DESCENT
OF THE COMMAND MODULE ON THE MAIN PARACHUTE^a v_W - Concluded

(b) Three parachutes

v_W range		Cumulative frequency
m/sec	ft/sec	
7.90	25.91	0.0
8.14	26.70	.90
8.30	27.22	3.60
8.46	27.75	8.28
8.62	28.27	18.91
8.78	28.79	42.51
8.94	29.32	67.75
9.10	29.84	85.23
9.25	30.36	93.88
9.42	30.89	96.94
9.57	31.41	98.20
9.73	31.93	99.28
9.89	32.46	99.64
10.05	32.98	100.00

^aThese data are based on a CM updated weight of 5368.4 kilograms (11 835 pounds). To account for the updated weight of the CM, a correction factor $v_W(\text{new}) = v_W(\text{old}) \sqrt{W(\text{new})/W(\text{old})}$ was used. Data for the updated CM are currently being made available.

TABLE V. - CUMULATIVE DISTRIBUTION FUNCTION FOR THE
UNRESTRICTED WINDSPEED u_W

u_W range, knots	Cumulative frequency	u_W range, knots	Cumulative frequency
0.0	0.0	50.674	95.9
6.757	2.0	54.052	97.3
13.513	10.0	57.430	98.8
20.270	22.6	59.120	99.4
27.026	38.2	60.809	99.55
33.783	55.7	62.498	99.7
40.539	76.6	64.187	99.85
43.917	85.0	65.876	99.95
47.296	90.0	67.565	100.00
48.984	95.0		

TABLE VII. - NUMBER OF TIMES STRUCTURAL CAPABILITY WAS EXCEEDED AND PROBABILITY OF SUCCESS
FOR VARIOUS APOLLO WATER LANDINGS^a

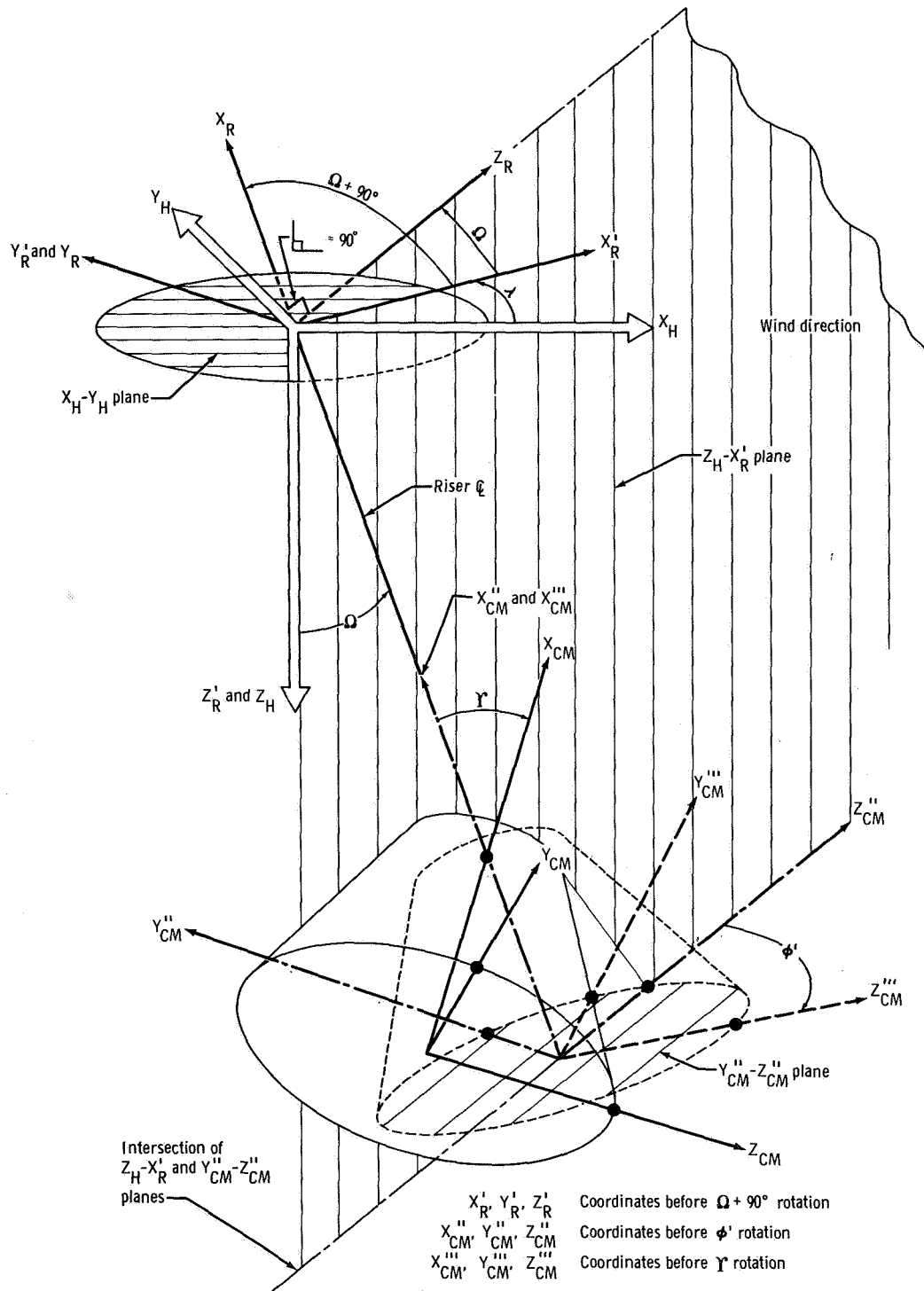
Initial conditions				V _N		V _T		Combination	
u _W , knots	u _W , knots	Two-parachute probability, percent	Sea state	Structural capability exceeded, no. of times	Probability structural capability not exceeded	Structural capability exceeded, no. of times	Probability structural capability not exceeded	Structural capability exceeded, no. of times	Probability structural capability not exceeded
Factor of safety = 1.0									
37.7	28.5	1.0	f(u _W)	61.0	0.99939	425.0	0.99575	486.0	0.99514
Variable	Variable	1.0	f(u _W)	10.0	.99990	14.0	.99986	24.0	.99976
32.48	24.5	1.0	f(u _W)	21.0	.99979	.0	1.00000	21.0	.99979
43.1	32.5	1.0	f(u _W)	185.0	.99815	11 384.0	.88616	11 569.0	.88431
37.7	28.5	25.0	f(u _W)	171.0	.99829	510.0	.99490	681.0	.99319
37.7	28.5	100.0	f(u _W)	510.0	.99490	825.0	.99175	1 335.0	.98665
37.7	28.5	1.0	0	.0	1.00000	414.0	.99586	414.0	.99586
Variable	Variable	1.0	0	.0	1.00000	14.0	.99986	14.0	.99986
Factor of safety = 1.1									
37.7	28.5	1.0	f(u _W)	118.0	0.99882	2 022.0	0.97978	2 140.0	0.97860
Variable	Variable	1.0	f(u _W)	23.0	.99977	88.0	.99912	111.0	.99889
37.7	28.5	1.0	0	.0	1.00000	2 030.0	.97970	2 030.0	.97970
Variable	Variable	1.0	0	.0	1.00000	76.0	.99924	76.0	.99924
Factor of safety = 1.35									
37.7	28.5	1.0	f(u _W)	837.0	0.99163	13 445.0	0.86555	14 278.0	0.85722
Variable	Variable	1.0	f(u _W)	191.0	.99809	884.0	.99116	1 075.0	.98925

^aBased on 100 000 simulated impacts.

TABLE VIII. - PROBABILITY OF OCCURRENCE OF THE BODY X-AXIS
DECELERATION LOADS^a

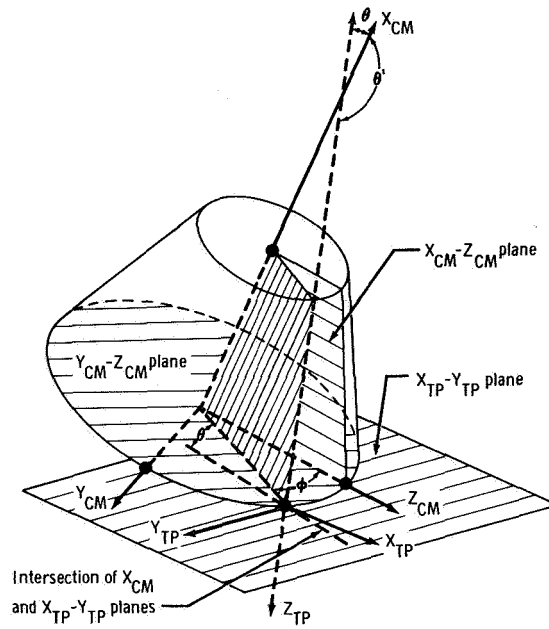
Initial conditions				Body X-axis deceleration, g		
u'_W , knots	u_W , knots	Two-parachute probability, percent	Sea state	0.3 percent	Mean	99.7 percent
37.7	28.5	1	$f(u_W)$	≈ 0.0	7.76	29.9
37.7	28.5	25	$f(u_W)$	$\approx .0$	8.77	34.4
37.7	28.5	100	$f(u_W)$	1.2	12.2	39.5
Variable	Variable	1	$f(u_W)$	$\approx .0$	7.34	24.6
43.1	32.5	1	$f(u_W)$	$\approx .0$	8.21	34.0
32.48	24.5	1	$f(u_W)$	$\approx .0$	7.65	28.0
19.9	15.0	1	$f(u_W)$	1.2	7.22	20.8
13.3	10.0	1	$f(u_W)$	2.1	6.94	17.4
.0	.0	1	$f(u_W)$	2.5	6.66	15.7
37.7	28.5	1	0	2.5	6.65	15.7
Variable	Variable	1	0	2.5	6.65	15.7

^aBased on 100 000 simulated impacts.

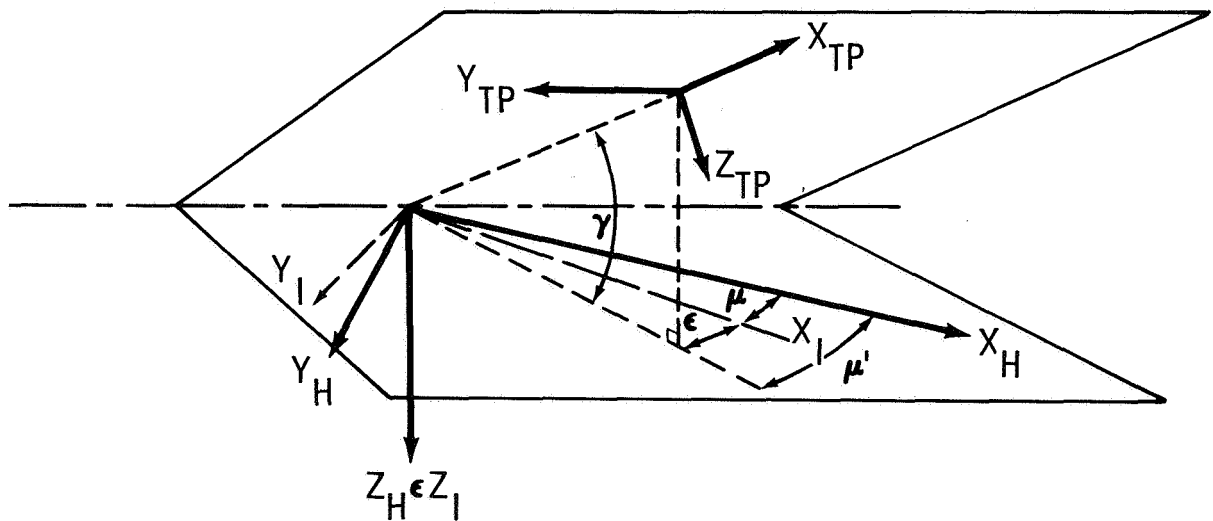


(a) Local horizontal, riser, and spacecraft axis systems.

Figure 1. - Coordinate systems and Euler angle relationships.



(b) Angular relation of the spacecraft to the impact tangent plane.



(c) Horizontal, wave, and impact-tangent-plane axis systems.

Figure 1. - Concluded.

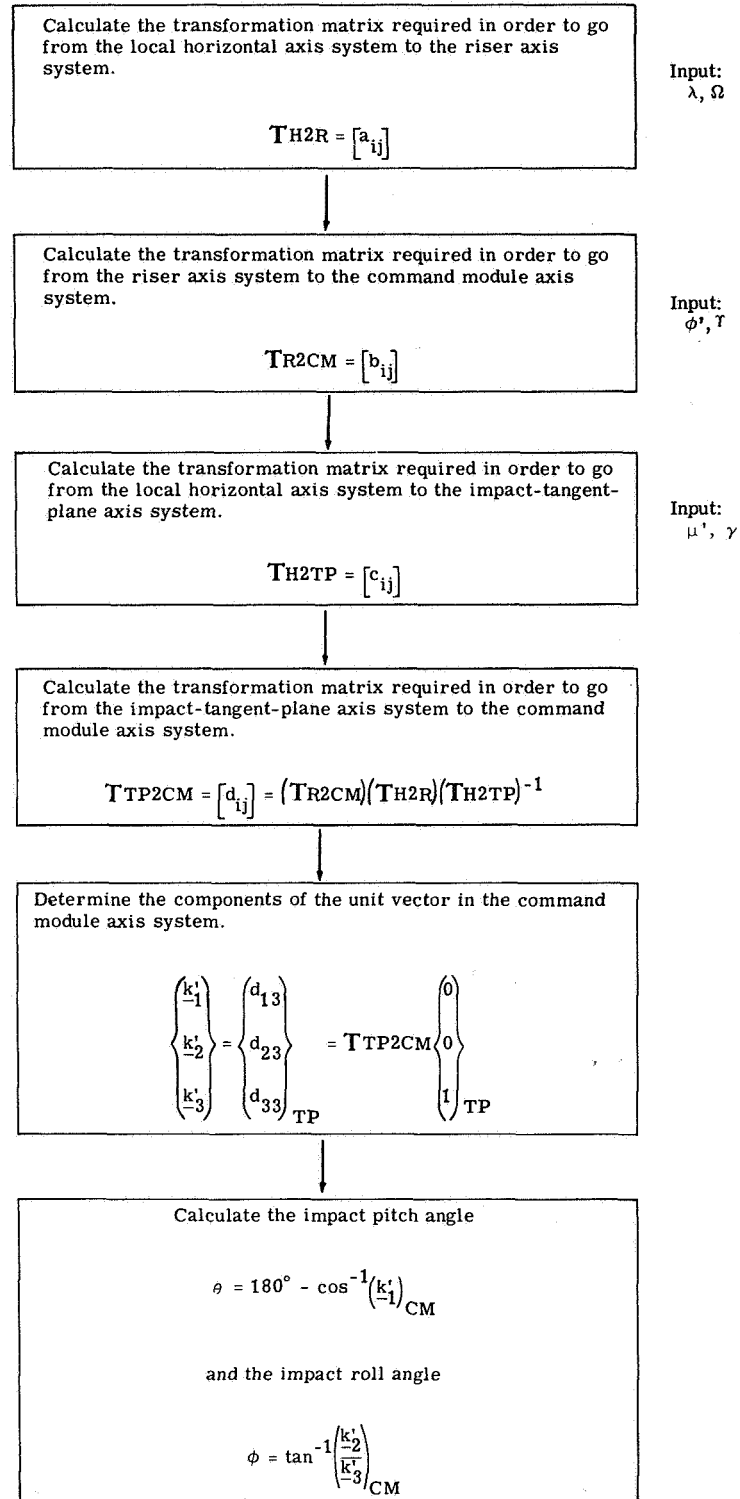
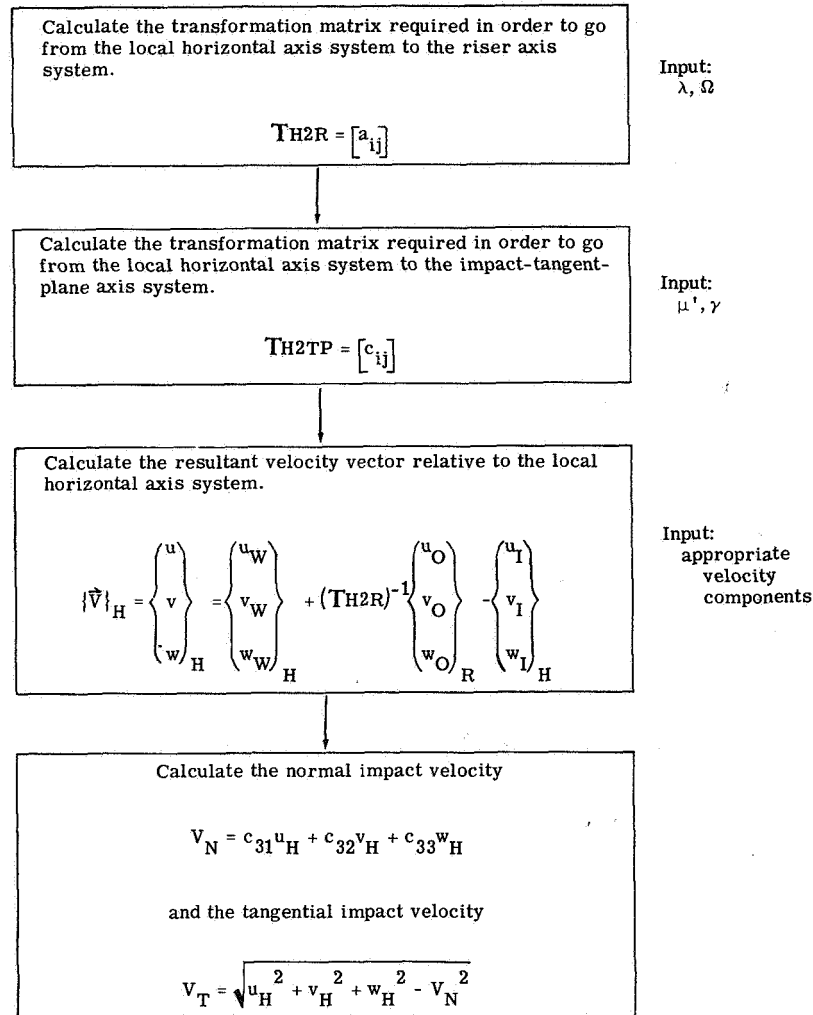


Figure 2. - Landing-simulation flow diagram.



(b) Impact velocity.

Figure 2. - Concluded.

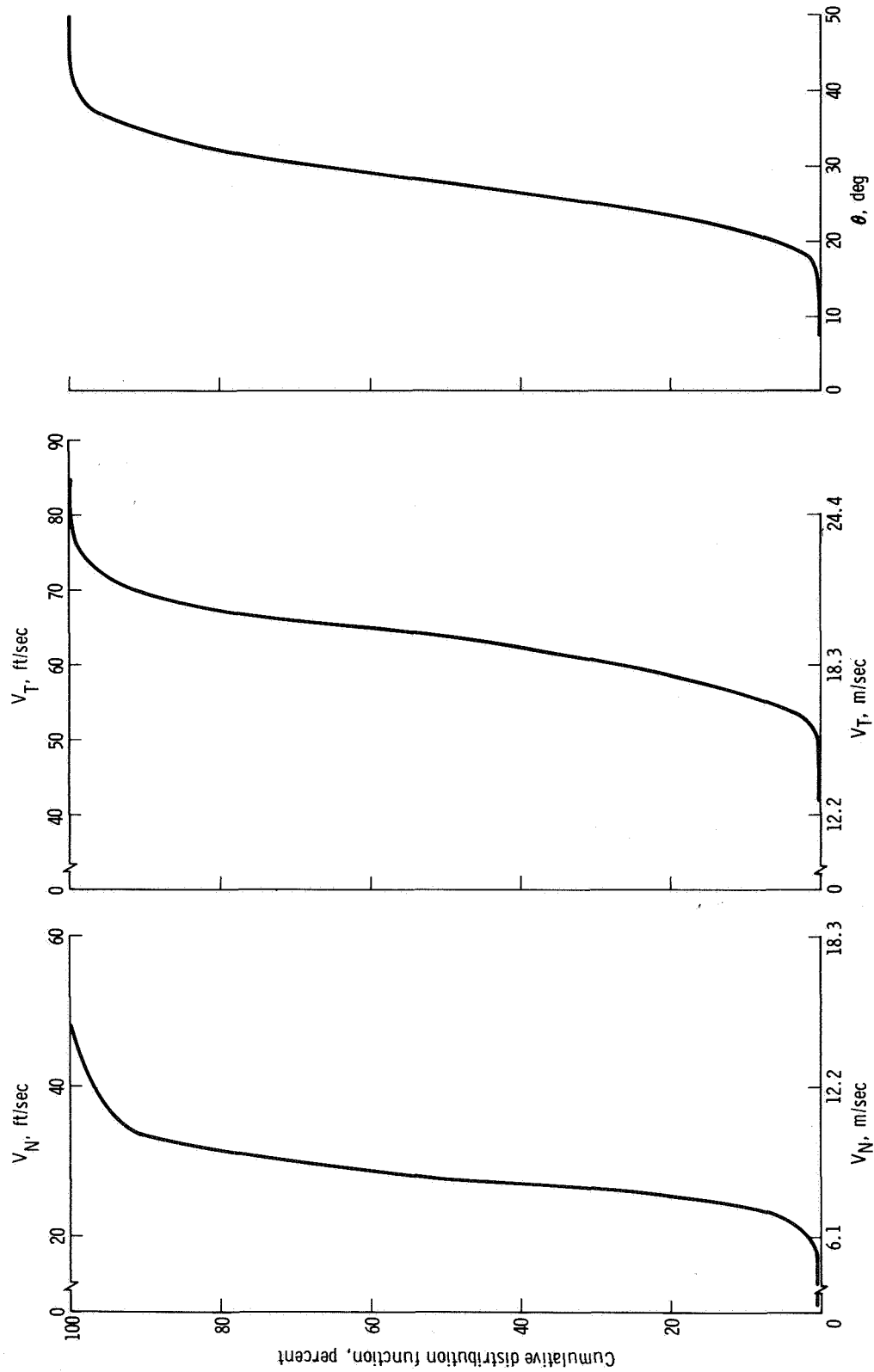


Figure 3. - Cumulative frequency distribution of water impact conditions for a fully developed sea with a fixed 28.5-knot surface wind and a 1-percent two-parachute probability.

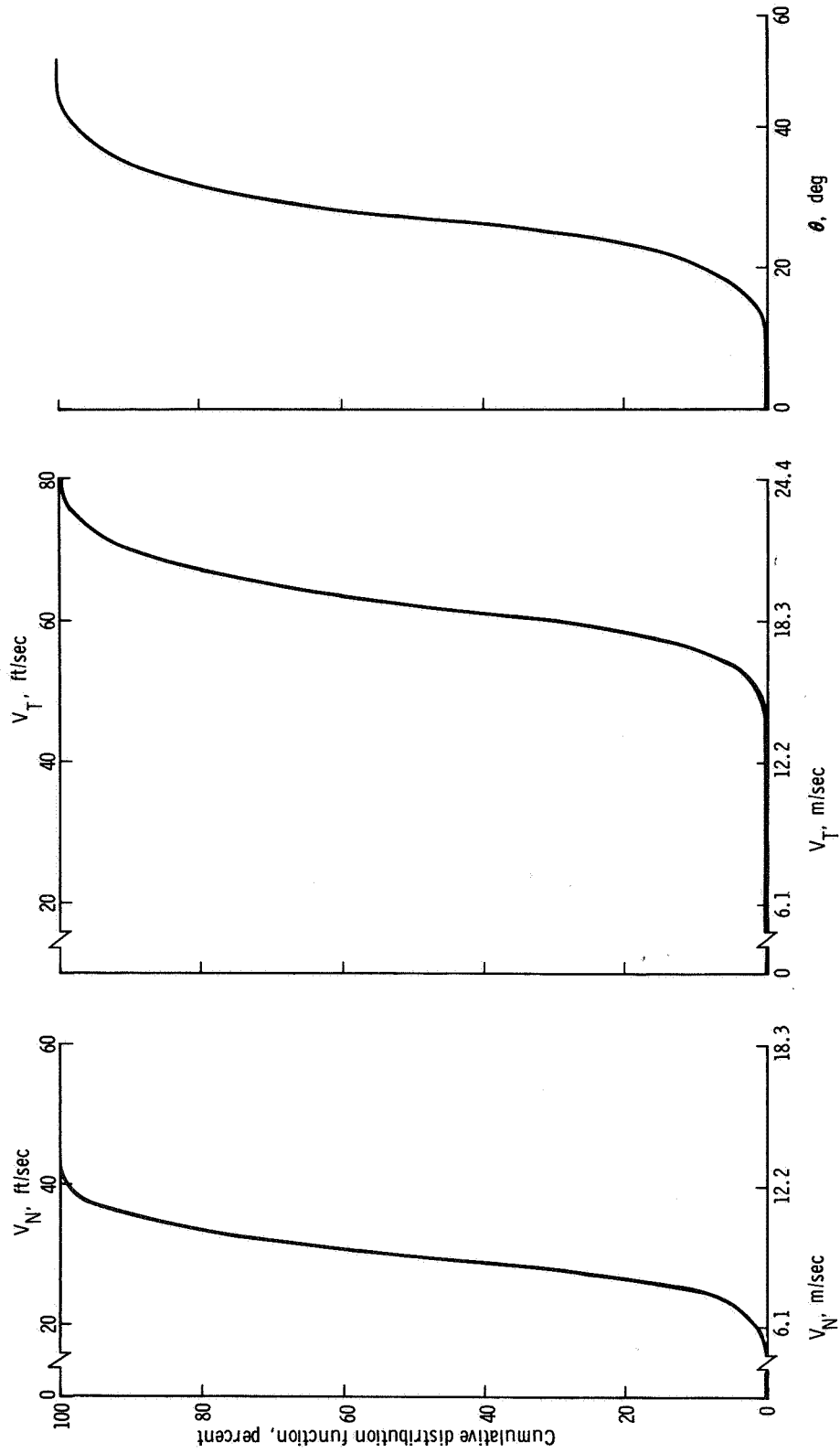


Figure 4. - Cumulative frequency distribution of water impact conditions for a fully developed sea with a fixed 28.5-knot surface wind and a 25-percent two-parachute probability.

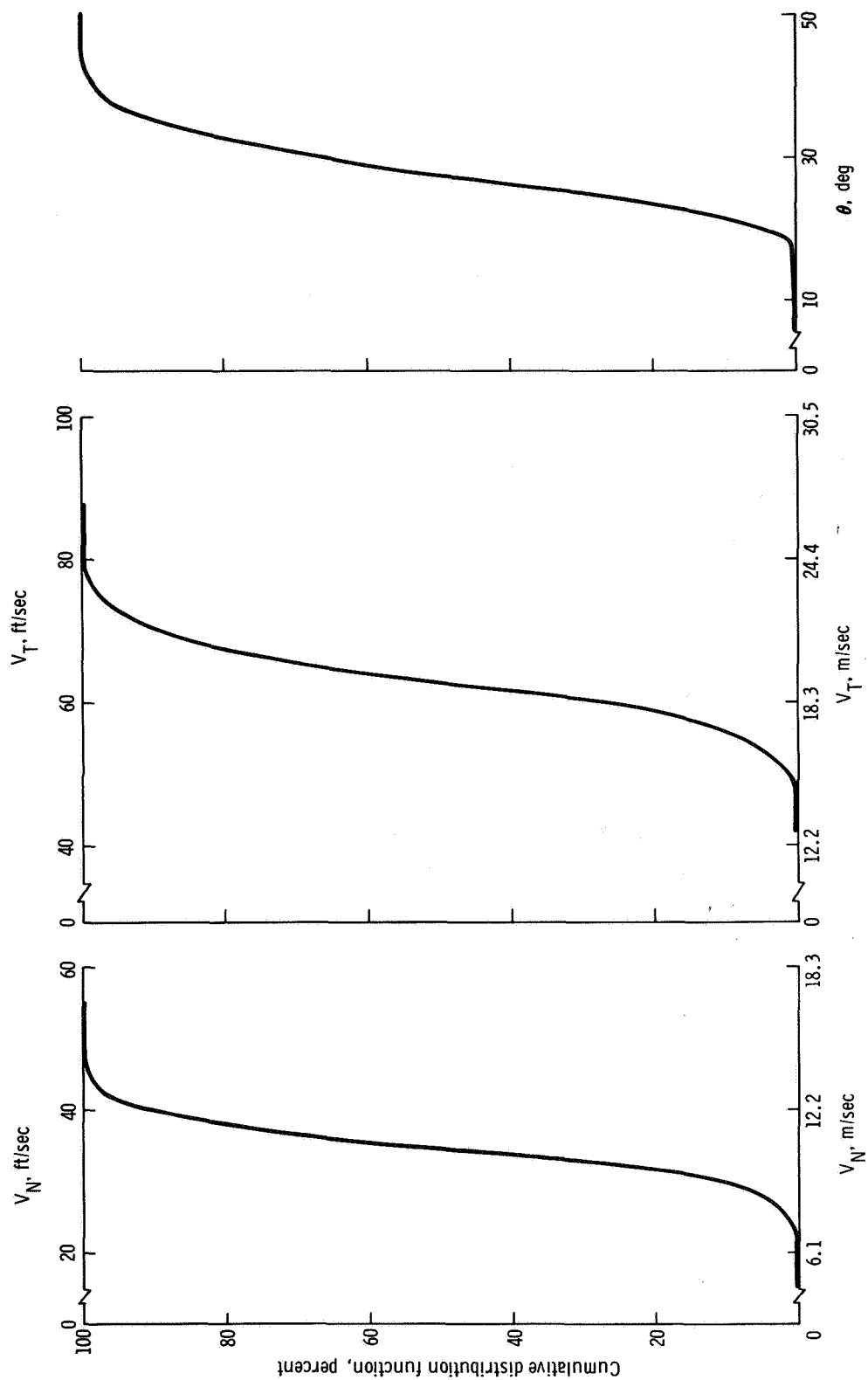


Figure 5. - Cumulative frequency distribution of water impact conditions for a fully developed sea with a fixed 28.5-knot surface wind and a 100-percent two-parachute probability.

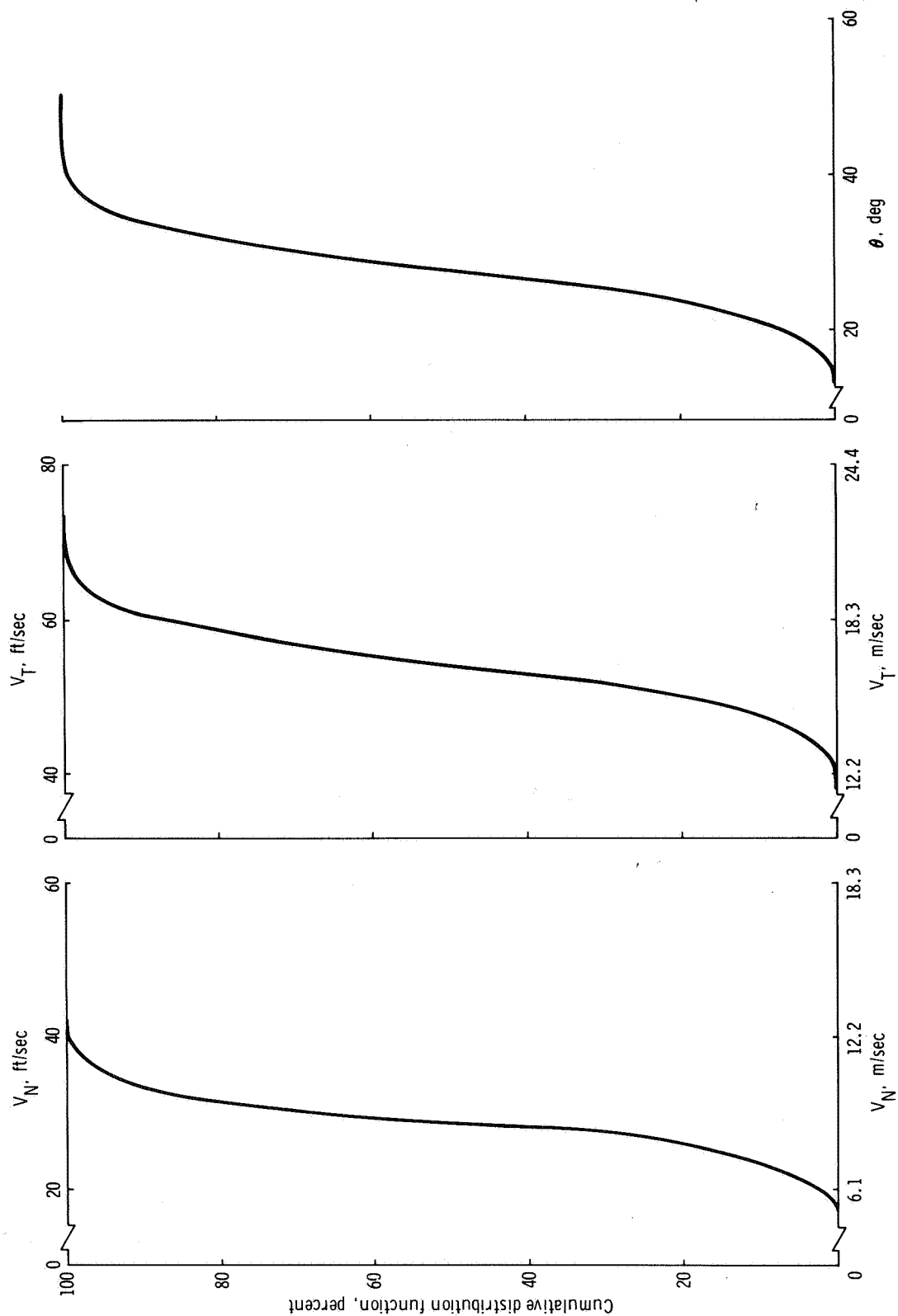


Figure 6. - Cumulative frequency distribution of water impact conditions for a fully developed sea with a fixed 24.5-knot surface wind and a 1-percent two-parachute probability.

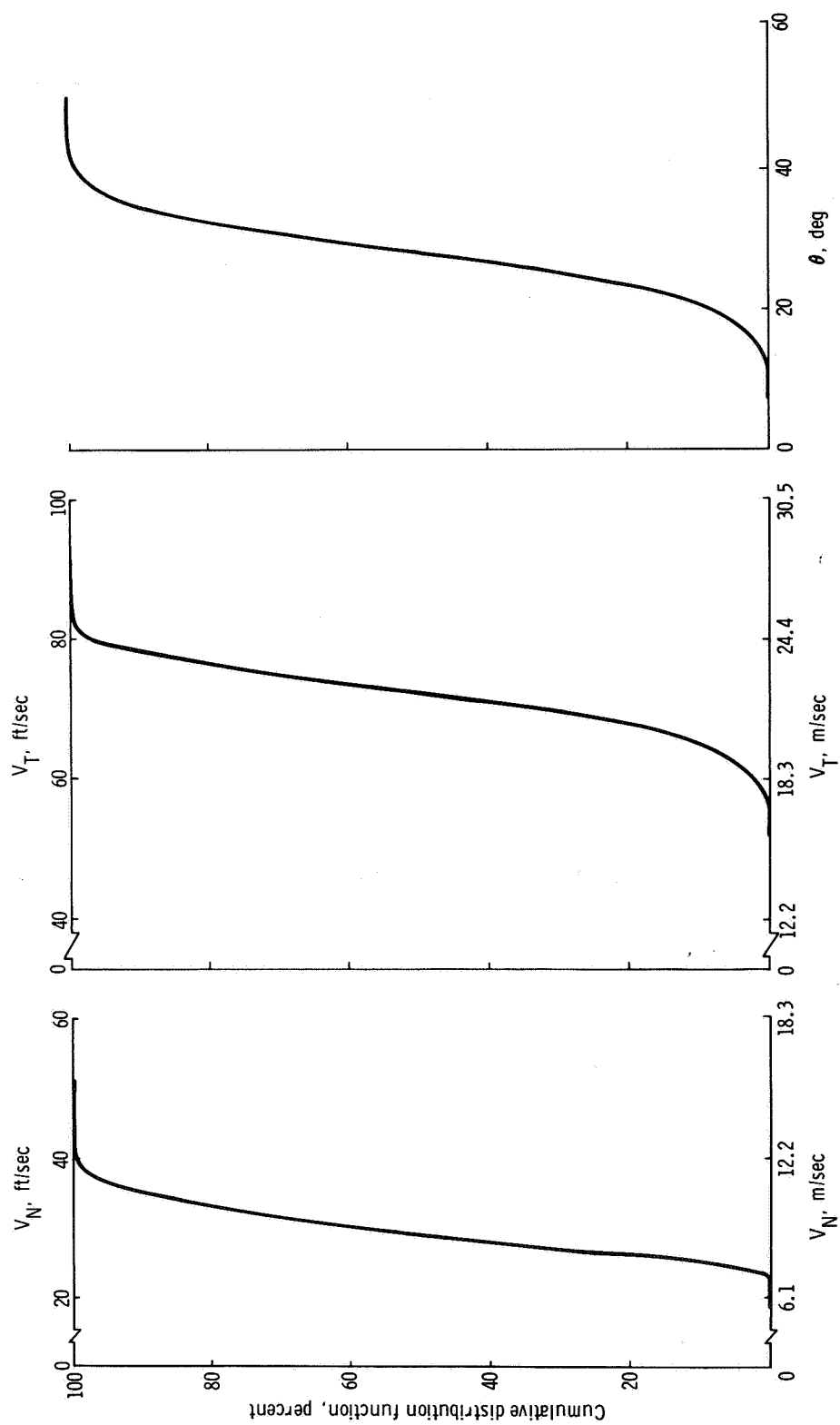


Figure 7. - Cumulative frequency distribution of water impact conditions for a fully developed sea with a fixed 32.5-knot surface wind and a 1-percent two-parachute probability.

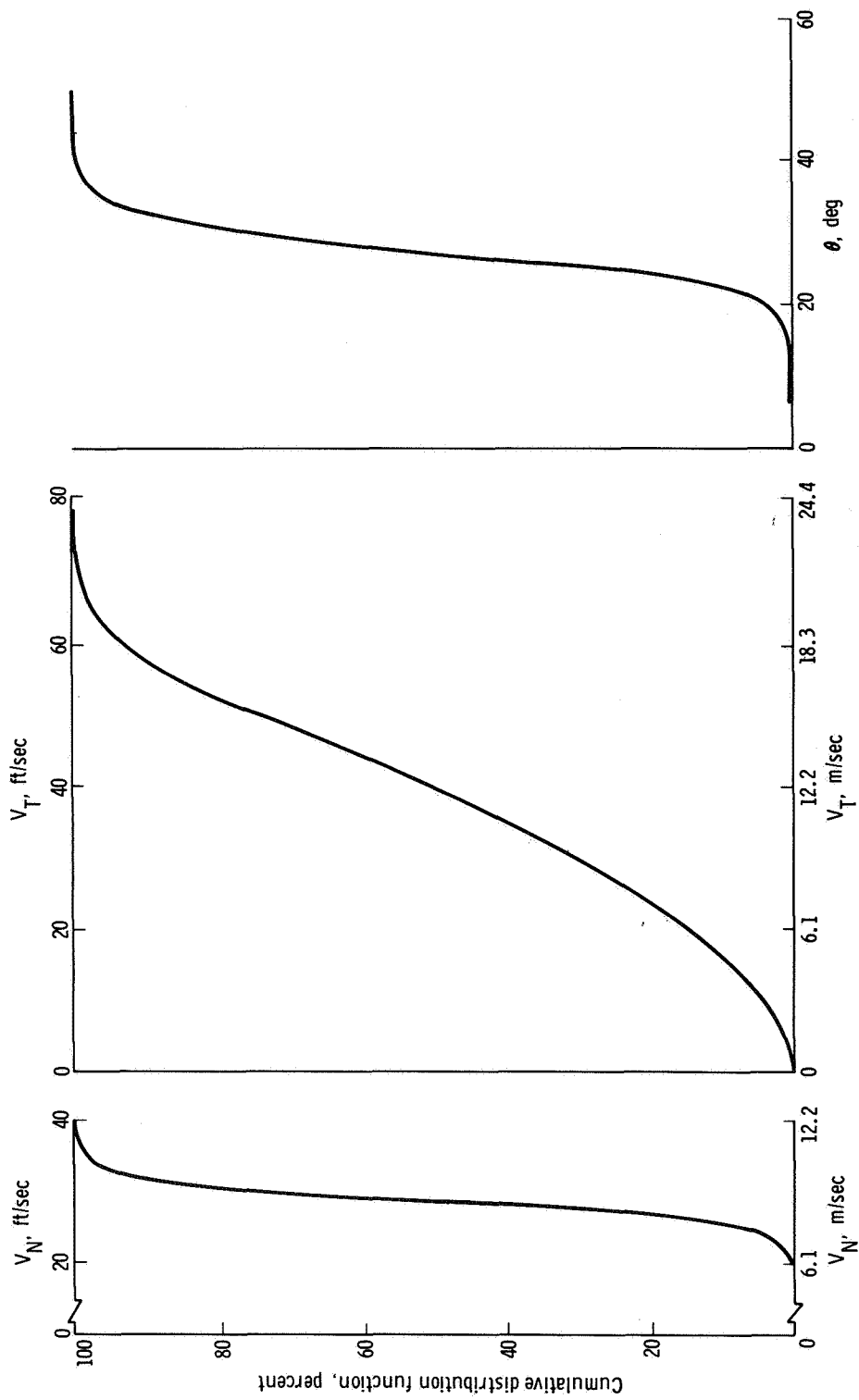


Figure 8. - Cumulative frequency distribution of water impact conditions for a fully developed sea with a variable surface wind and a 1-percent two-parachute probability.

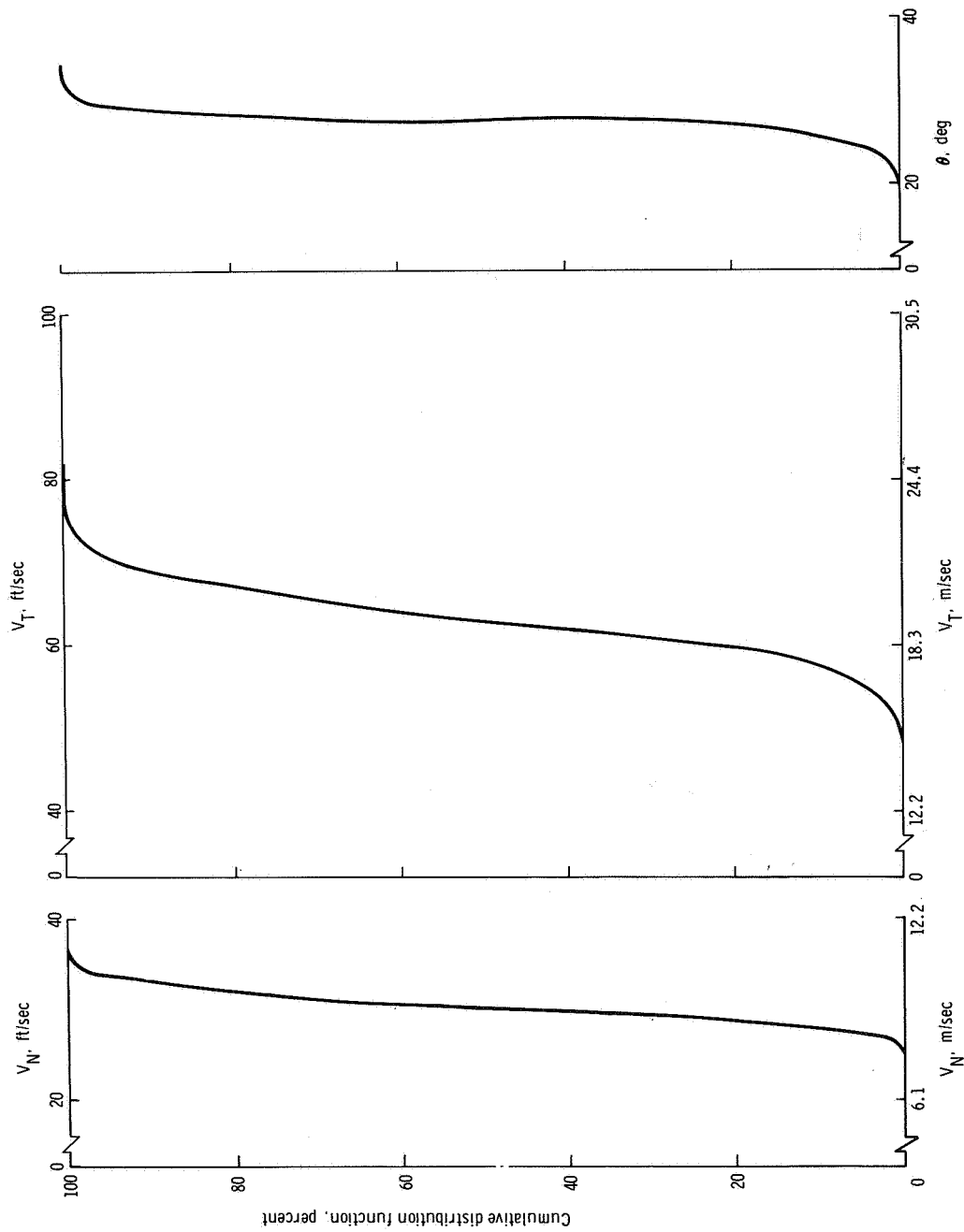


Figure 9. - Cumulative frequency distribution of water impact conditions for a fully developed sea with a fixed 28.5-knot surface wind, a calm sea, and a 1-percent two-parachute probability.

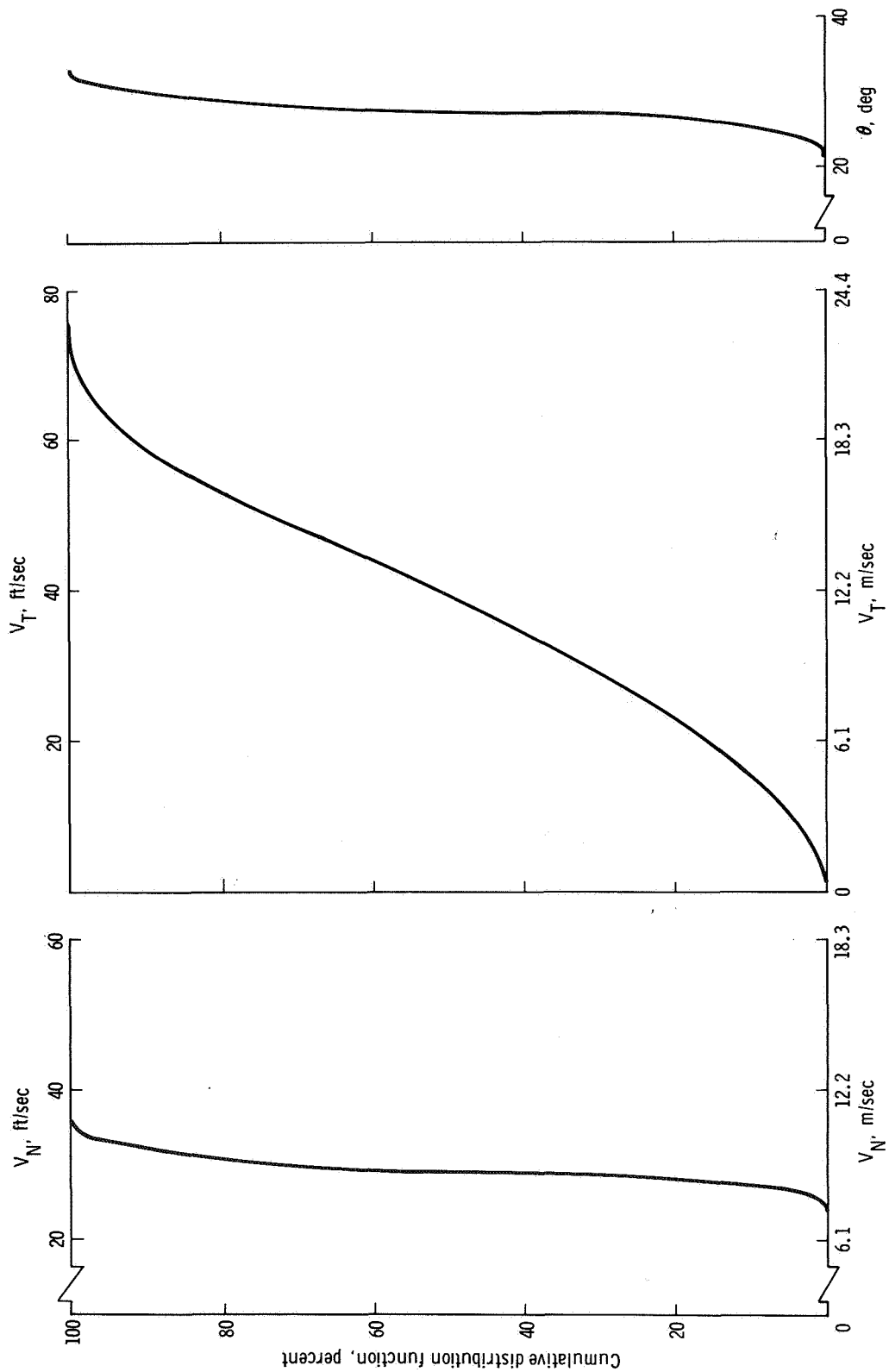
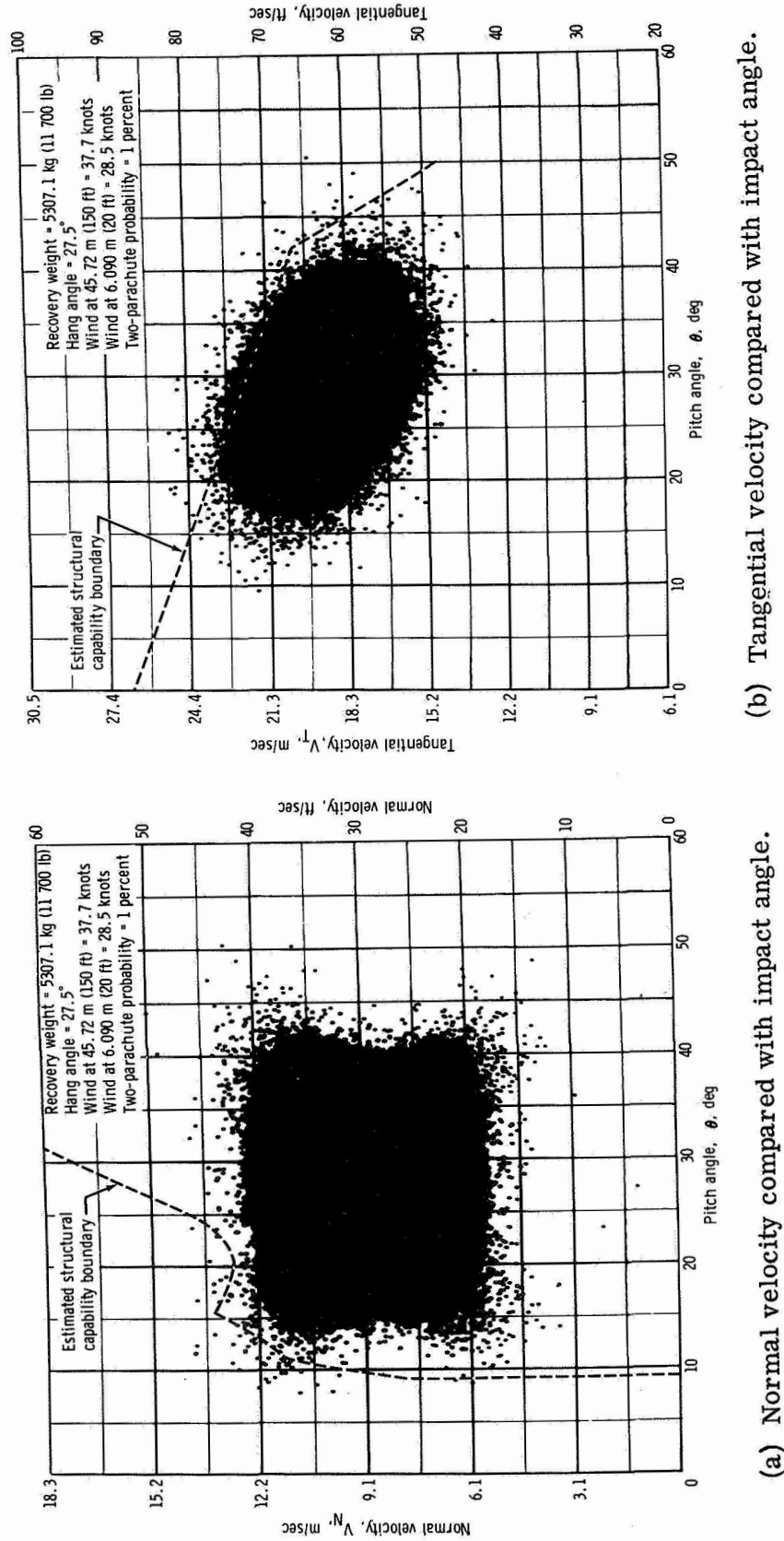


Figure 10. - Cumulative frequency distribution of water impact conditions corresponding to a variable surface wind, a calm sea, and a 1-percent two-parachute probability.



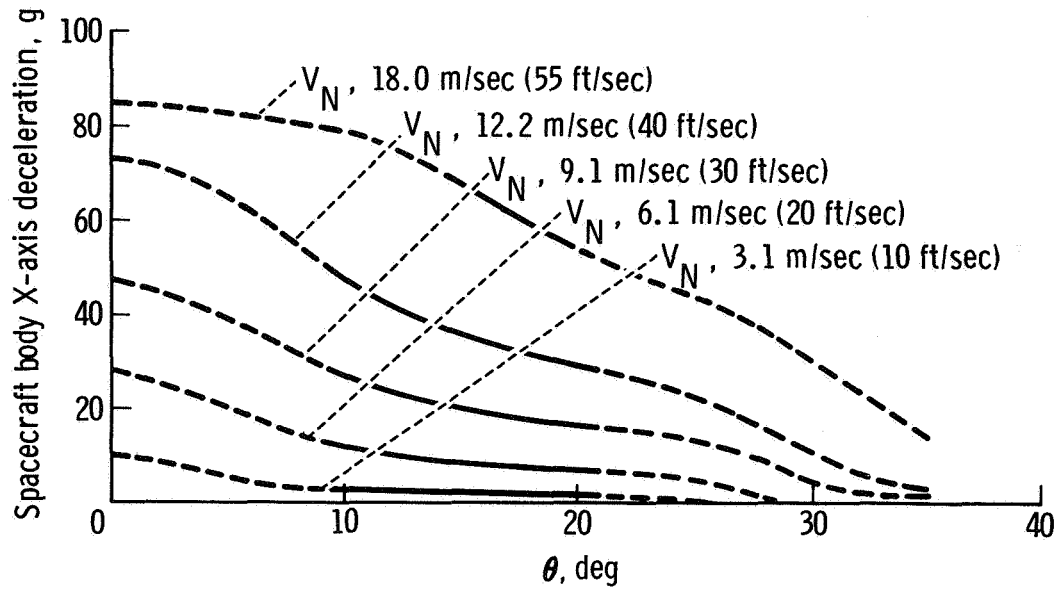


Figure 12. - Spacecraft body X-axis deceleration as a function of normal velocity and impact angle.

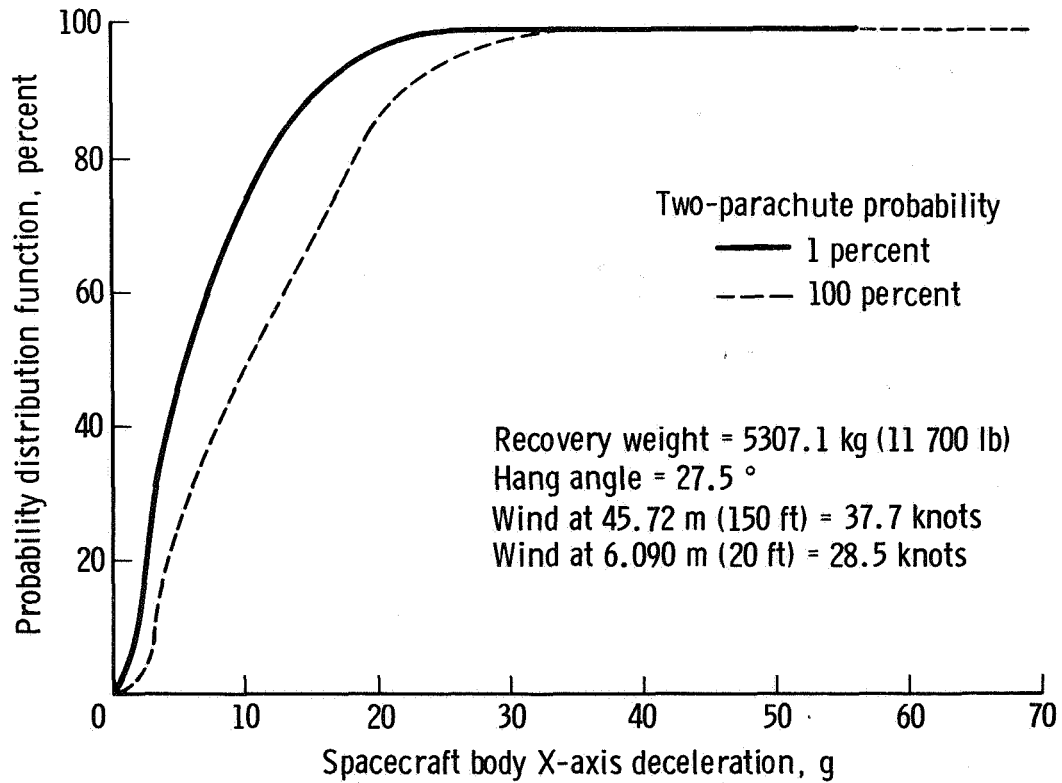


Figure 13. - Cumulative frequency distribution for body X-axis deceleration in water impact conditions of a fully developed sea with fixed 28.5-knot surface wind and a 1-percent to 100-percent two-parachute probability.

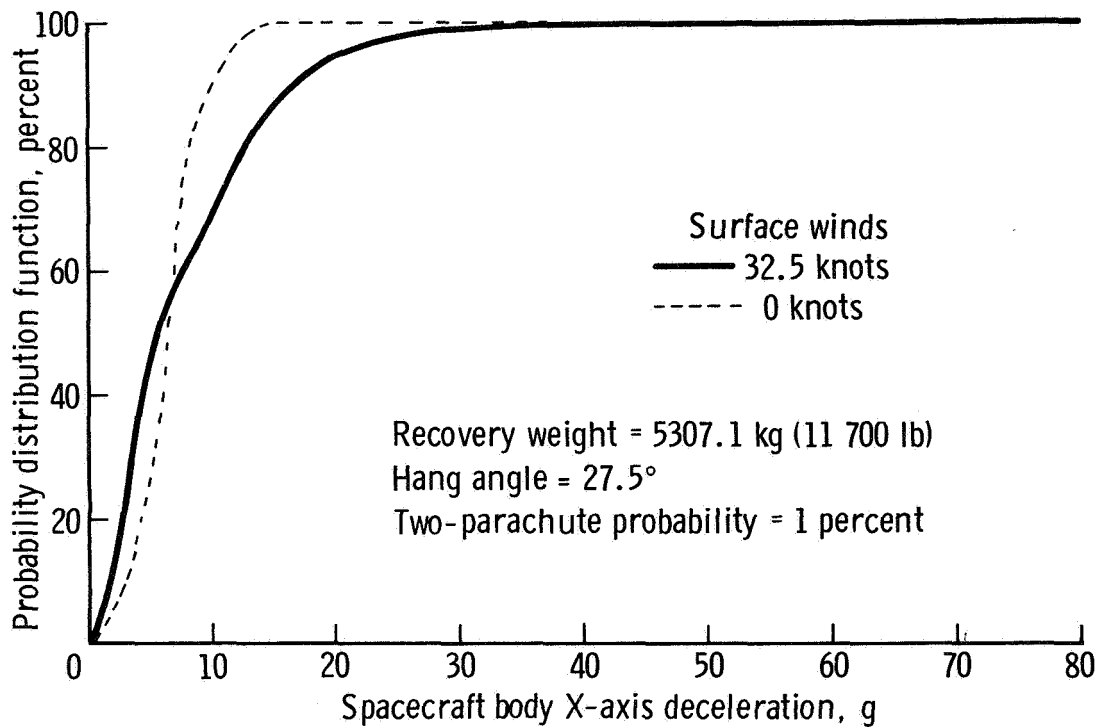


Figure 14. - Cumulative frequency distribution for body X-axis deceleration in water impact conditions of a fully developed sea with fixed 0- and 32.5-knot surface winds.

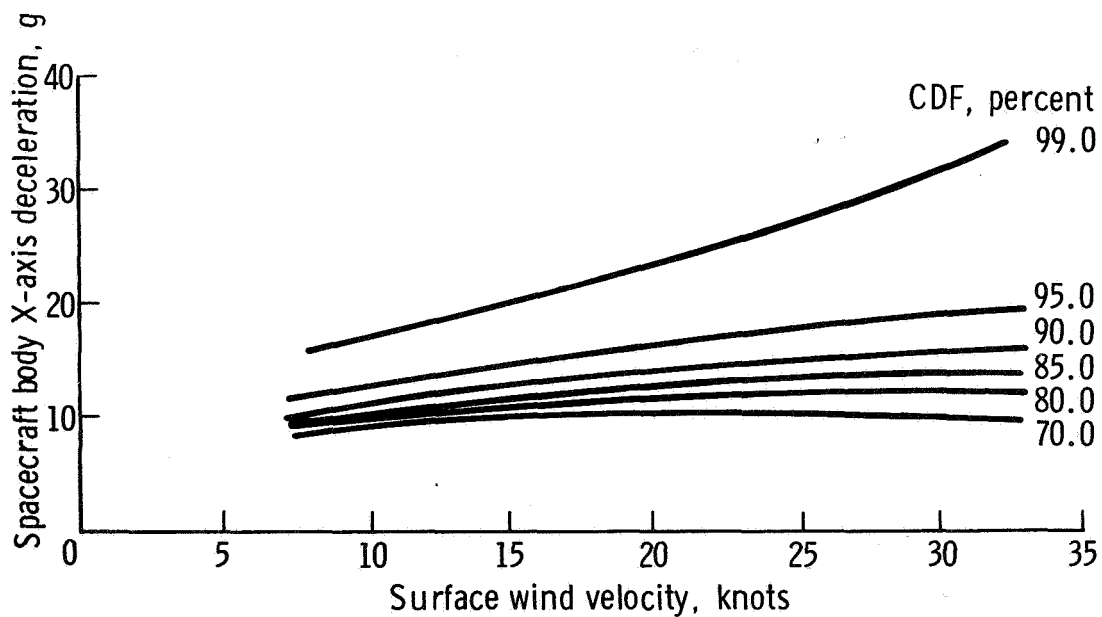


Figure 15. - Variation of the body X-axis decelerations with fixed surface winds for given probabilities of occurrence.

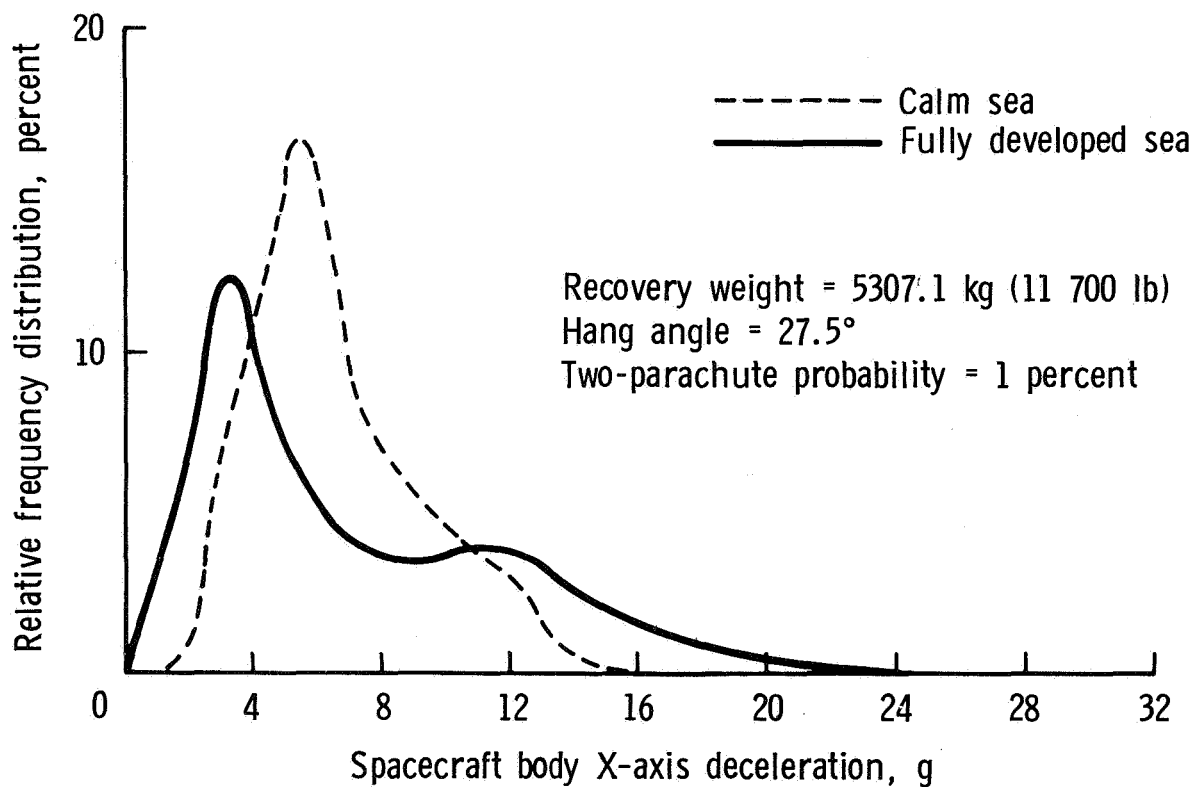


Figure 16. - Relative frequency distribution for body X-axis deceleration in water impact conditions of sea states ranging from a calm sea to a fully developed sea with a fixed 28.5-knot surface wind.

1. Report No. NASA TM X-2430		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle STATISTICS CONCERNING THE APOLLO COMMAND MODULE WATER LANDING, INCLUDING THE PROBABILITY OF OCCURRENCE OF VARIOUS IMPACT CONDITIONS, SUCCESSFUL IMPACT, AND BODY X-AXIS LOADS				5. Report Date November 1971	
				6. Performing Organization Code	
7. Author(s) Arthur M. Whitnah and David B. Howes, MSC				8. Performing Organization Report No. MSC S-255	
				10. Work Unit No. 914-50-11-09-72	
9. Performing Organization Name and Address Manned Spacecraft Center Houston, Texas 77058				11. Contract or Grant No.	
				13. Type of Report and Period Covered Technical Memorandum	
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546				14. Sponsoring Agency Code	
15. Supplementary Notes					
16. Abstract Statistical information for the Apollo command module water landings is presented. This information includes the probability of occurrence of various impact conditions, a successful impact, and body X-axis loads of various magnitudes.					
17. Key Words (Suggested by Author(s)) * Command Module Water Landing * Probability of Successful Impact * Various Impact Conditions * X-Axis Deceleration Loads * Analytical Model				18. Distribution Statement	
19. Security Classif. (of this report) None		20. Security Classif. (of this page) None		21. No. of Pages 36	
				22. Price \$3.00	



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